Fractal Analysis on the Correlation of Coastal Line Geometry and Tsunami Impact in Maumere, Flores, Indonesia

SARI BAHAGIARTI KUSUMAYUDHA*, LISTYANI**, HERU SIGIT PURWANTO*, A.G. ISJUDARTO**
* UPN "Veteran", Jl SWK 104, Condongcatur, Yogyakarta 55283, Indonesia
**STTNas, Jl Babarsari, Yogyakarta 55281, Indonesia
E-mail: saribk@gmail.com

Abstract

Almost all of the Indonesian territories are high potential of geologic disaster, such as earthquake, tsunami, volcanic eruptions, and landslides, because the country belongs to tectonically active. There are three big lithosperic plates interact one another influencing the tectonic setting of Indonesia. The plates are Indo-Audtralia Plate, Eurasia Plate and Pasific Plate. Indo-Australia Plate moves relatively northward by about 9 cm/year rate, Eurasia Plate creeps southeastward with approximately 7 cm/year speed, and Pacific Plate moves to the west with around 11 cm/year velocity. In the meeting line of the plates, about 300 km to the south of Indonesian Islands, there is the subduction zone that become to be places of where earthquake focuses are generated. Earthquake from submarine source with more than 6.5 magnitude is potencial to generate tsunami. Areas situated along the south coast of Indonesia islands are vulnerable to tsunami, because directly facing the boundary lines between Eurasia Plate and Indo-Australia Plate. This study verified that there is positive correlation between coastal line geometry and the tsunami impact, based on fractal analysis. The case study is Maumere, Flores island, East Nusa Tenggara, Indonesia. Result of the study is expected able to be used for predicting the tsunami impact intensiveness at other areas.

Keywords: fractal geometry, coastal line, tsunami, plate tectonics

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Introduction

Most of the Indonesian territories are highly potential of geologic disasters, such as earthquake, tsunami, volcanic eruptions, and landslides, because the country belongs to tectonically active. The tectonic setting of Indonesia is influenced by three main plate interactions. The plates are Indo—Audtralia Plate, Eurasia Plate and Pasific Plate. The most sensitive places of Indonesia to tsunami are areas located in the southern coast of Indonesian islands, because they are directly facing the plate boundaries between Eurasian Plate and either Indo-Australian Plate or Pacific Plates. The study was done in Maumere, Flores island (Figure 1).

On 12th of December 1992 there was earthquake and tsunami disaster in Maumere and its surrounding areas, killing thousands people and damaging millions rupiah values of infrastructures. There was a phenomenon that coast area with a specific shoreline geometry more vulnerable to tsunami than others. Therefore, in order to assess the correlation of curve geometry of coastal line and the intencity of tsunami impact, this study was done by applying fractal analysis. Results of the study is expected able to be used to predict the impact intencity of tsunami in other areas with similar coastal line characteristics.

Method of Study

This study combined field geologic surveys and fractal analyses, utilizing both primary and secondary data. Application of fractal analysis in this study is to quantify the coastal lines curve values in the study area. Despite prepared on desk while determining fractal dimension, field surveying was also done in order to acquire data on geological condition and tsunami impact including victims and damages. The secondary data on victims were derived from local government offices.

Fractal scaling system is specified by non-integer numbers so called fractal dimension (Bunde & Havlin, 1994). Determination of fractal dimension is important in practical quantification problems. It helps find out the correlation of fractal objects and processes working on them. In order to compute fractal dimension in this study, box-counting method was applied, done by drawing grids with certain length side (r) over the fractal objects. Then the fractal dimension (D) is determined using equation:

$$D = \lim_{r \to \infty} \frac{\log Nr(F)}{-\log r} \qquad (1)$$

Where $Nr(F)$ is the number of boxes that cover the fractal set (F), and r is the length of the box side. The computation of $Nr(F)$ is repeated by changing the length of the box side (r), so that r approaches zero. $Nr(F)$ values and r are plotted on a log-log graph to derive the fractal dimension, e.g., the slope of the plot (Tricot 1996).

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To obtain fractal dimension values, the shorelines along the study area were divided into 28 segments. The division were based on their curve pattern similarity, obtained from topographic map of 1 : 25.000, and air photos of tracing of 1 : 30,000 scales. The fractal dimension of every coastal line segment was then determined by box counting method. Next, values got from the fractal dimension computation were compared to field data and informations, especially related to the impact of tsunami had ever happened.

Geology

According to USGS (2005) data, the relative plates motions of Eurasia is southeastward by 4 cm/ year, Indo-Australia is northward by about 7 to 9 cm/ year, and Pacific is westward by 11 cm/year. Eurasia Plate meets Indo-Australia Plate along the southern part of Sunda and Nusa Tenggara Islands from Sumatra, Jawa to Nusatenggara.

Flores island belongs to East Nusa Tenggara Islands. Shape of the island is unique, bordered by a rough geometric of coastal line, with some active volcanoes in the middle parts. Some of the volcanoes are Ili Lewotobi Laki-laki (1584 m), Ili Lewotobi Perempuan (1703 m), Keli Bara (1631 m), Keli Mutu (1640 m), Mount Iya (659) m, Mount Rokatenda (P. Palue, 875 m), and Egon Mountains in the eastern Flores with some highs of 1703 m and 1838 m above sea level.

The oldest rock formation of Flores is Miocene age, consists of volcanic breccia, lava, basaltic to ryolitic tuff sandstone. This rock unit is interfingered to Nangapanda Formation that consists of calcareous fine grain clastic sediments and limestones. The rocks are unconformably overlain by volcanic products of Pliosen to Quaternary age. The youngest Rock units are coral limestone, coastal terrace deposits, and coastal alluvium deposits (Suwarna, et.al., 1990).

Nusa Tenggara islands including Flores are charactrized by complex geologic structures. There are some faults formed from plates interactions, crosscutting Flores island generally striking northeast – southwest and northwest – southeast. They not only exist in the south but also in the north parsts of the island. The transformal and trust faults in the noth part often creat shallow destructive earthquake.

Flores Earthquake and Tsunami, 12 Desember 1992

Tsunami is usually triggered by seafloor earthquake of more than 6.5 magnitude. When subducting plate breaks, resulting crust deformation, there will be volumetric spatial change bringabout sea water

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absorbed into the space of deformation. This causes in general the occurrence of tsunami. It is initially started with seawater level drop for several meters to kilometers after the earthquake. Later, there will be such a great wave comes back to the shore with high velocity and destructive energy. This happens due to hydrostatic and hydrodynamic balancing to reach its stability.

Some coastal areas of Indonesia especially those facing the plate boundaries are vulnerable to tsunami (Figure 2). Since 1901 to 2006 period, there were more than 75 great tsunamis happenned in Indonesia, about 85% of them occurred in the eastern part of Indonesia, including Nusa Tenggara islands where Flores located. Maumere eventhough situated in the northpart of Flores, is not able to avoid tsunami risk. This is caused by some transformal faults as the result of interaction between Pacific Plate, Eurasia Plate, and Indo-Australia Plate. The subduction and transformal faults control the existence of active faults striking northeast – southwest and northwest – southeast of Flores.

There was a tectonic earthquake followed by tsunami attacking Flores in Saturday, 12th of December 1992 on 13.30 pm in the local time. The disaster destructed Maumere, the capital city of Sikka Region and Larantuka of East Flores Region, were influenced by back arc tectonic activity along the north of East Nusa Tenggara Islands. The tsunami killed 2.080 people and damaged infrastructures of Sikka Region. Infrastructures were destructed including hauses, offices, schools, and many others. Thousands missed their hauses and jobs (Satlak PB Sikka Region, 1994).

Acording to the Board of Meteorology and Geophysics (BMG) of Kupang (2007), the earthquake source was located under the seafloor, on the coordinate of 8,42^o South Latitude and 122,10^o East Longitude, 36 km depth, 30 km distance of northrn Maumere, with magnitude of 6,8 Richter scale; and 7,5 Richter scale. The earthquake then generated tsunami. The tsunami attacked about 300 m into the land area, with almost 10 m high of the wave. Wave hight in the harbour was 4 meters (BMG Kupang, 2007). The tsunami also beat the Babi island, north of Maumere (850 people died), Pamana island north of Flores, Kalautoa island of Selayar Region, and South Sulawesi Province (killed 20 people, and damaged some buildings).

Results and Discussion

Indonesia belongs to a country with the longest shorelines and most potential of tsunami disaster on the world. According to Rahardjo (2005) coastal line configuration determine how serious the damage caused by tsunami. Sub marine geomorphology and bathimetry influence how strong and high the

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tsunami wave coming to the beach. The morphology of the shores of Maumere, as any other coastal areas, there will be high potential when the coast has a gulf or fyords. Factors influencing the shape are lithology, geomorphology, and geologic structures of the area. Despite those geologic factors, exodynamic processes such as abrasion and coastal sedimentation also play important role. Curve of coast lines belong to fractal geometry. Ranges of fractal dimensions (D) of the coastal lines can be grouped into four, i.e. D = 1 - 1,05, D = 1,05 - 1,1, D = 1,1 – 1,15, and D = 1,15 – 1,2, that can be seen in the Table 1 (See Figure 3).

Coast with fractal dimension > 1 is usually displaying fjord and embayment morphology, there is intensive sedimentation, and influenced by the existence of active faults. Comparing the values of fractal dimension of the coastal lines in the study area and the impact of tsunami in the past time, there is a positive correlation of fractal dimension value and the impact intensiveness. The higher the fractal dimension of the coastal lines, the more serious the damage of the area, including the number of people died. Based its intensiveness, tsunami impact on coastal lines correlated to their fractal dimension can be indexed as 0, 1, 2, and 3, and classified into four classes, e.g. safe, low, medium, and high (Table 3). There is positive correlation beetwen value of fractal dimension and the seriousness of tsunami impact. Impacts of tsunami Maumere 12 December 1992 were listed in the Table 3, while Figure 4 shows the correlation of fractal dimension of coastal lines in the study area and tsunami impact intensiveness.

Alok is a district of which fractal dimension value of the coast equals to 1.09. Although this value is not so high, but in fact, when the tsunami happened, this area suffered from serious damage and too many human victims. This was caused by the situation of Wuring, a village of fishers with very dense population in this district. At that time, the community of Wuring village built their houses too close to the open sea (Satlak PB Sikka region, 1994). Therefore a major destruction was not able to be avoided.

Conclusions

1. Due to the tectonic setting of Indonesia, most of the southern coastal lines, which facing the subduction zone of Indo-Australia plate and close to some transform faults are high potential for tsunami
2. Tsunami destroyed Maumere and surrounding area in 1992 was caused by back arc transformal fault movement triggered by the subduction activity of Indo-Australia Plate beneath Eurasia Plate.

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3. Based on tsunami impact intensiveness and its fractal dimension, coastal lines in the study area can be classified into "safe" with fractal dimension 1 – 1.05, "low" with fractal dimension 1.05 – 1.1, "medium" with fractal dimension 1.1 – 1.15, and "high" with fractal dimension > 1.2
4. There is a positive correlation between the fractal dimension value of the coastal lines geometry and impact intensiveness of tsunami in Maumere area. The higher the fractal dimensions of the coastal line geometry, the more serious the damage of the area by tsunami.
5. Despite correlated to morphology of the coastal line, expressed by its fractal dimension, the seriousness of tsunami impact also depends on the population of the area, as shown by Alok district.

References

Badan Meteorologi dan Geofisika (BMG), Kupang, 2007, History of Tsunami in Flores 1992

Bunde, A. & Havlin, S., 1994, Fractals in Science, Springer Verlag, Amsterdam, 298p.

Bupati Kepala Daerah Tingkat II Sikka, 1993, Report on earthquake and tsunami 12th December 1992, Sikka Region, 5th – 6th July 1993

Harjadi P., 2008, Earth environmental aspect and monitoring system, Proc. Seminar on Trend of Earth Science Researches, Bandung 28th October 2008, 64-71

Kusumayudha, S. B., Zen, M.T., Notosiswoyo, S., Gautama, R.S 1999, Fractal analysis of the Oyo river, cave systems and topography of the Gunungsewu karst area, Central Java, Indonesia, Hydrogeology Journal Vol 8 No 3, 271–278.

Kusumayudha, S.B., 2002, Mapping landslides vulnerable areas by fractal analysis: An alternative method, Proc Symposium of Sediment Disaster Prevention, S.T.C, 251-256.

Kusumayudha, S.B 2004, The application of fractal geometry analysis to groundwater exploration, *Research Basin and Hydrological Planning*, A. A. Balkema Publishers, p 207–213.

Latief, H. dkk. 2005, Tsunami Aceh, Tsunami Research Group, Marine Research and Development Group, Institute of Technology, Bandung.

Mandelbrot, B.E., 1983, The Fractal Geometry of Nature, W.H. Freeman & Co., Springer Verlag, New York, 468 p.

Rahardjo, P. P., 2005, Impact of earthquake and tsunami of Nanggroe Aceh Darussalam, Proc of Discussion on post disaster mitigation of Aceh earthquake and tsunami, University of Parahyangan, Bandung.

Satlak PB Sikka Region, 1994, Report on disaster mitigation of earthquake and tsunami 12th December 1992, Sikka Region, 12th January 1994.

Suwarna, N., Santosa, S. dan Koesoemadinata, S., 1990, Geologic map of Ende, Nusa Tenggara Timur, Sheets 2207, 2208, 2307, 2308, skala 1 : 250.000, Pusat Penelitian dan Pengembangan Geologi, Bandung.

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Tricot, C. (1996). Curves and Fractal Dimension, Springer Verlag, New York, 323 p.

USGS, 2005, Preliminary earthquake report for the west coast of Northern Sumatra (2004 December 26 00:58:53 UTC), United States Geological Survey, USGS alert, Retrieved, March 3, 2005.

http://serc.carleton.edu/NAGTWorkshops/visualization/collections/tsunami.htm.

http://sim.nilim.go.jp/GE/SEMI2/Proceedings/Makalah%203.doc, Penggunaan citra untuk memantau perubahan dan kerusakan kawasan pantai.

http//www.indonesiamercycorp.org, (2005), Post Disaster Programs.

http://www.geocities.com/kliping

http//serc.carleton.edu, (2005)

Table 1. Segments of Coastal Line and Fractal Dimensions of Maumere, Flores.

District Name	Location Name	Segment Number	D Box
Palue	P. Palue / Tepetetu - Natu	1	1
	P. Palue / Waraloo	2	1.02
	P. Palue / Wolo Manunai - Nitunglea	3	1
	P. Palue / Watupuli	4	1.02
Nita	Bt. Lipilongo - Fata	5	1
	Tg. Liatua	6	1.02
	Kalisia	7	1.09
	Wolo Nusakutu - Wolowarnokarua	8	1.02
	Wolowarnokarua - Wairii	9	1
Alok	Nangahure - Wailiti	10	1
	Bebeng - Kotauneng - Wuring	11	1.09
	Wairotang -Waioti	12	1
Kewapante	Waipare - Kewapante	13	1.01
Waigete	Nangahale - Wairita	14	1
	Wairita	15	1.02
	Waigete - Nangahalelama	16	1
Talibura	Nangahale - Wairmude	17	1
	Lemiwair	18	1.09
	Nangamerah-Langloeng	19	1.05
	Baukremut - Kabal	20	1
	Tanahdewa	21	1.13
Maumere	P. Babi	22	1.17
Paga	Iliwolokoli - Paga	23	1

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Legebai	Bhera - Wara	24	1
Lela	Tiget - Sikka	25	1
Bola	Hokor - Waigete - Doreng	26	1
	Hebing	27	1,02
	Hebing	28	1,04

Tabel 2. Classification of Tsunami Impact Intensiveness

Class	Died (% of total population)	Injuried (% of total population)	Material lost (billions Rp)	Houses damages (number)	Infrastructure damage (% of total existing)	Impact Seriousness Index
High	>25	>25	≥ 50	≥1500	≥ 75	3
Medium	15 - 25	20 - 25	25 – 50	250 - 1500	50 – 75	2
Low	2 - 15	5 - 20	2- 25	50 – 250	25 - 50	1
Safe	0 - 2	0 - 5	≤ 5	≤ 50	≤ 5	0

Tabel 3. Fractal Dimensions and Tsunami Impacts.

Name of District	Fractal Dimension	Number of Human Victims		Amount of Lost (billions Rp)	Infrastucture Damages
		Died	Injuried		
Alok	1.04	144	1359	76.31	193.17
Maumere	1.17	791	127	59.35	190.14
Nita	1.02 – 1.09	16	158	48.42	249.21
Lela	1	13	80	9.45	174.13
Paga	1	14	21	7.07	149.56
Kewapante	1.01	9	100	11.05	239.14
Bola	1.02	28	27	5.4	185.96

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Talibura	1.05 – 1.09	82	57	12.67	180.49
Palue	1.02	8	10	2.57	88.89
Waigete	1.02	1	7	5.79	152.12
Legebai	1	7	36	8.56	144.42

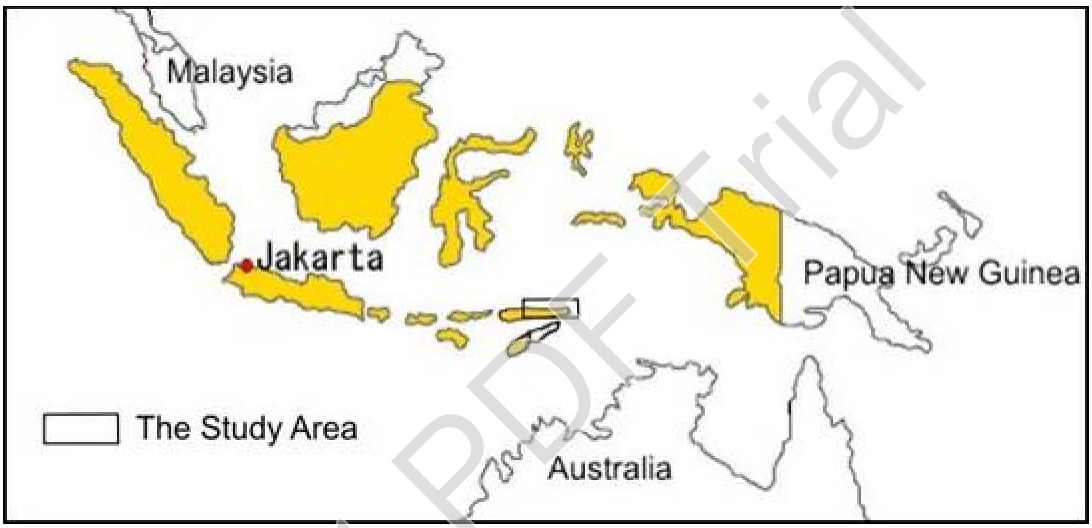

Figure 1. Location of the study area.

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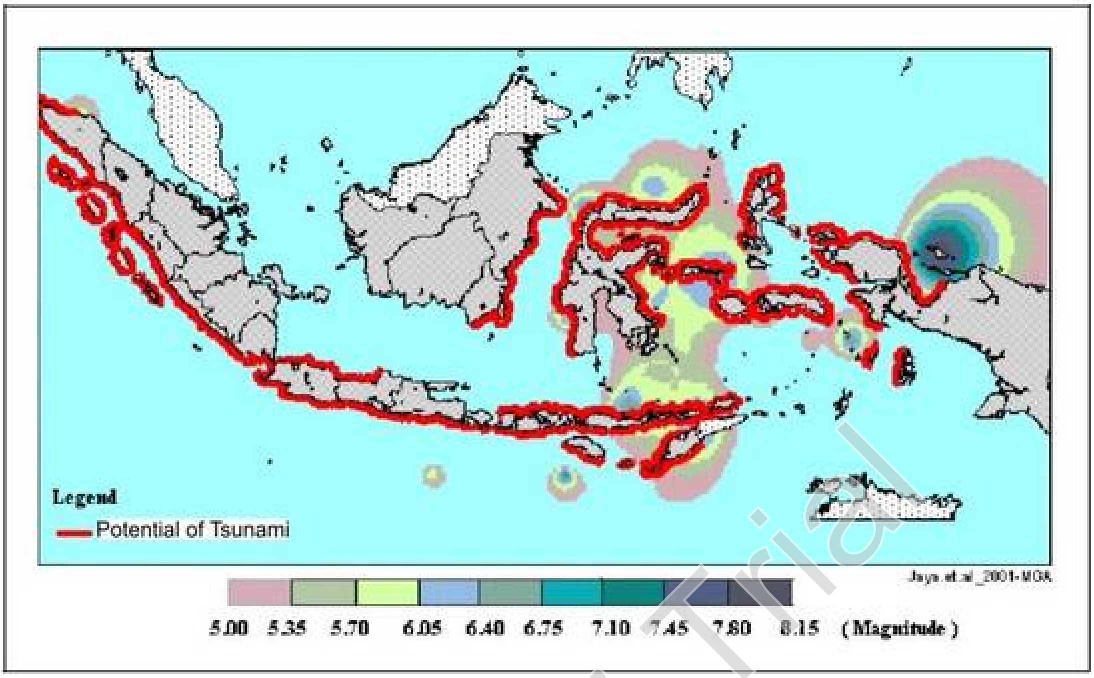

Figure 3. Map showing coastal lines (red color) which are potential of subjected to tsunami (http//serc.carleton.edu, 2005).

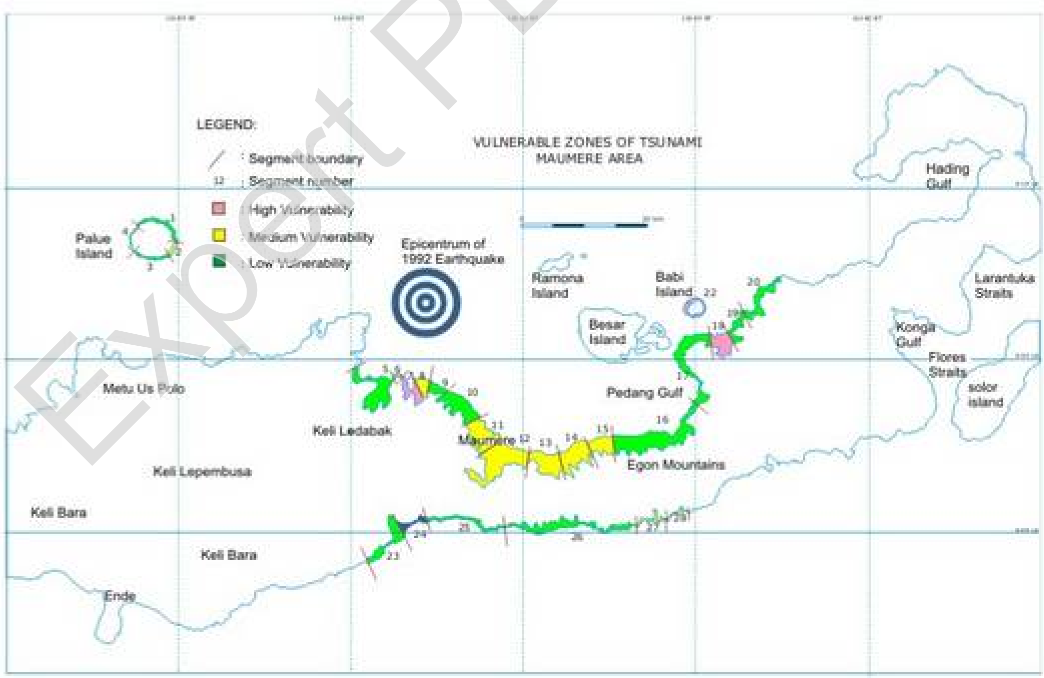

Figure 3. Segments of coastal line and tsunami vulnerability of Maumere and surrounding area, Flores.

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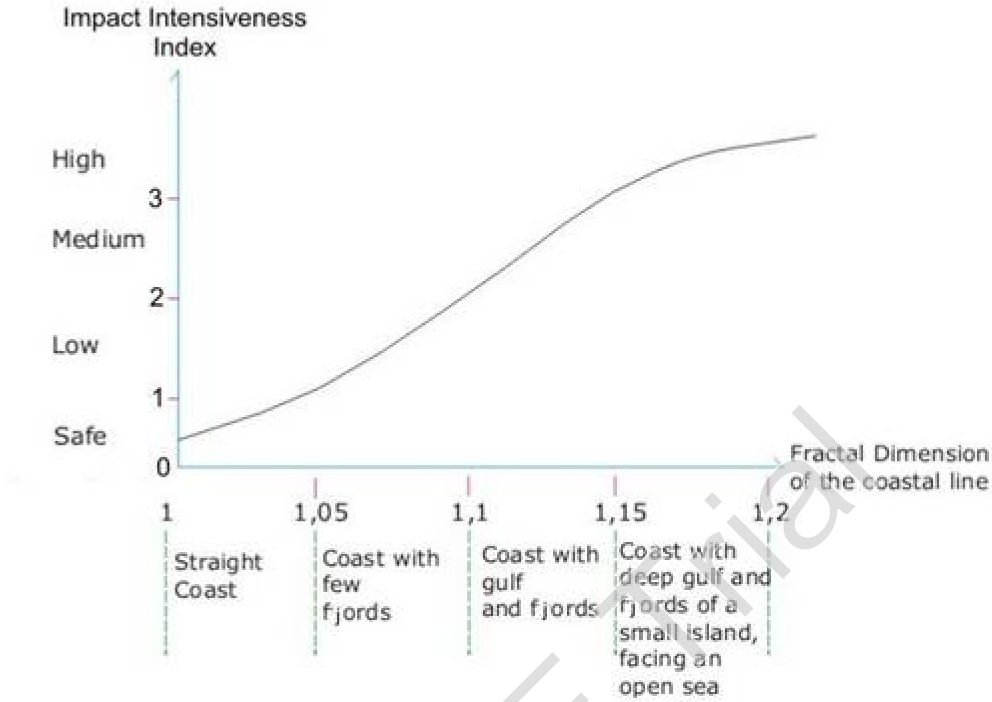

Figure 4. Correlation of coastal line fractal dimension and tsunami impact intensiveness, Maumere, Flores

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